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π^0 ELECTROPRODUCTION AND TRANSVERSITY

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Abstract

Exclusive π^0 electroproduction and related processes are suggested to investigate the chiral odd transversity distributions of quarks in the transversely polarized nucleon, $h_1(x)$, and its first moment, the tensor charge. The connection between a description based on partonic degrees of freedom, given in terms of generalized parton distributions, and Regge phenomenology is explored.

1 Introduction

Most of the information on the partonic structure of hadrons has been traditionally obtained through inclusive deep inelastic experiments. With an appropriate selection of probes and reactions, accurate measurements conducted through the years allowed one to map out in detail the different components

of proton structure, the Parton Distribution Functions (PDFs) in a wide kinematical region of the four-momentum transfer, Q^2 , and of the longitudinal momentum fraction of the proton's momentum, x_{Bj} . An inclusive/exclusive connection in lepton-nucleon scattering was advocated ¹⁾, although studies of the partonic structure through exclusive measurements remained ambiguous in establishing the regime of four-momentum transfer in which such a description should be valid. A new avenue was recently suggested in view of the factorization properties of new types of exclusive processes, namely Deeply Virtual Compton Scattering (DVCS), Deeply Virtual Meson Production (DVMP), and related crossed-channel reactions. The soft matrix elements, identified with Generalized Parton Distributions (GPDs), can describe both the intrinsic motion of partons and their coordinate space representation (see ^{2, 3)} for reviews). It is at present an outstanding problem to be able to reconcile and properly connect the newly suggested QCD-based picture with the hadronic description of hard exclusive reactions based on Regge theory. The latter is well known to predict a vast number of observations at large s , and small t , corresponding to the $x_{Bj} \rightarrow 0$ limit of inclusive Deep Inelastic Scattering (DIS). Initial studies of the correspondence between the regime expected to be dominated by Regge exchanges and the partonic description in DVCS and DVMP were performed in ^{4, 5)} where it was claimed that the “leading Regge trajectories should dominate the amplitudes for exclusive leptonproduction”. Therefore one might think of the hard exclusive process as probing the deep inelastic structure of a t -channel exchange target, or the mesonic cloud. On the other side, it was pointed out in Ref. ⁶⁾ that the model used in ^{4, 5)} might disagree with the perturbative QCD scaling violation pattern, which was recently observed in a particular (large W^2) kinematical regime. A formalism using the conformal moments of the nucleon GPDs was instead introduced with a non-perturbative input based on Regge ansätze.

Whether or not specific models are seemingly able to reproduce the current trend of data it is important to determine the physical origin of the hadronic structure that is detectable with hard exclusive scattering experiments aiming to shed light on the complementary picture where hadron structure at this transition regime emerges through QCD dynamics.

In this context we analyze a specific class of exclusive reactions, namely π^0 electroproduction with the goal of obtaining a relation between experimental

observables and the tensor charge.

2 Tensor Charge and Transversity

The chiral odd transversity distribution of quarks in the transversely polarized nucleon, $h_1(x)$, and its first moment, the tensor charge, δq , are defined as

$$\begin{aligned}\langle PS | \bar{\psi} \sigma^{\mu\nu} \psi | PS \rangle &= \delta q \bar{U}(P, S) \sigma^{\mu\nu} U(P, S) \\ &\equiv \delta q \, 2 (P^\mu S^\nu - P^\nu S^\mu),\end{aligned}\quad (1)$$

and

$$h_1(x_{Bj}, Q^2) = \Phi^\Gamma = \int dp^- d^2 \mathbf{p}_T \text{Tr} \{ \Gamma \Phi \} |_{x_{Bj} P^+ = p^+}, \quad (2)$$

with $\Gamma = i\sigma^{i+}\gamma_5$, and $\Phi(x; P, S)$ being the correlation function defining the matrix element for the DIS process ⁷⁾.

Notice that in the helicity basis ⁸⁾ h_1 corresponds to the off-diagonal quark chirality matrix elements

$$h_1 = \Phi_{+L, -R} + \Phi_{-R, +L} = q^\uparrow(x_{Bj}, Q^2) - q^\downarrow(x_{Bj}, Q^2) \quad (3)$$

originally introduced in ^{9, 10)} where the subscripts $\Lambda\lambda, \Lambda'\lambda'$ refer to the helicities of the proton (Λ, Λ'), and of the struck quark (λ, λ'). The connection between tensor charge and transversity is given by ⁷⁾:

$$\delta q = \int_0^1 h_1(x_{Bj}, Q^2) dx_{Bj} \quad (4)$$

In a non-relativistic scenario $h_1(x_{Bj}, Q^2)$ would coincide with the distribution of longitudinally polarized quarks in a longitudinally polarized proton, $g_1(x_{Bj}, Q^2)$. Its dynamical origin is therefore related to the relativistic motion of quarks in the nucleon.

Many attempts have been made to connect the tensor charge to measurable processes, the most successful of which have been through semi-inclusive DIS ¹¹⁾. Various theoretical approaches to modeling these quantities have been taken: from QCD Sum rules ¹²⁾ to Lattice QCD ¹³⁾ to phenomenological studies ¹⁴⁾. One particular approach to predicting the nucleon's tensor

charges, δu and δd has been the work of Gamberg and Goldstein¹⁶⁾. The tensor charges were calculated using approximate $SU(6) \otimes O(3)$ symmetry among the light axial vector mesons, an axial vector dominance hypothesis, and a generalization with re-scattering. This formalism which is based upon t -channel exchange is reminiscent of Regge Cut models on the one hand, depicted in Fig. 1, and the large s , small t (large u) $q\bar{q}$ pair (or to a t -channel exchange) or ERBL region of DVMP on the other hand, depicted in Fig. 2.

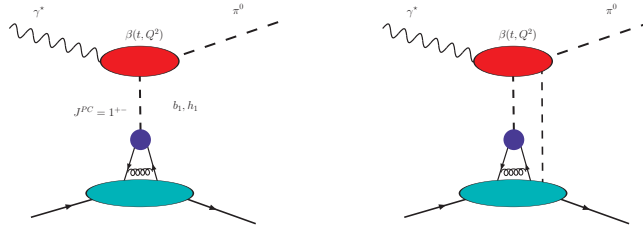


Figure 1: *The factorized Regge pole contribution to π^0 scattering is depicted.*

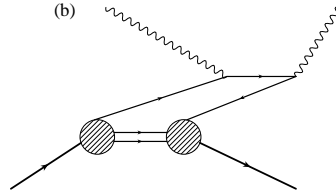


Figure 2: *Leading order diagram for DVCS in the ERBL^{14, 15)} region where a $q\bar{q}$ pair is first produced from the nucleon and subsequently interacts with the photons.*

This scheme yielded values for u and d quark tensor charges dependent on transverse momentum factors interpreted as transverse momentum transfer Δ_{\perp}^2 of the quarks in the nucleon. Δ_{\perp}^2 dependence suggests that re-scattering loop corrections must be present in single spin asymmetries in exclusive pion production^{17, 16)}. This approach left two open questions. First, the poles

in momentum transfer t are quite far removed from the relevant $t \rightarrow 0$ limit. Secondly, the charges depend on average values of the constituent transverse momenta, $\langle k_T^2 \rangle$. To address these questions and to develop a deeper understanding of the partonic underpinnings of transversity, we addressed them using the connection between GPDs and transversity recently studied in [18].

Note that $H_T(x, \xi, t)$, the Generalized Parton Distribution for transversity can be written as the off forward quark-target scattering amplitude, $A_{\Lambda\lambda, \Lambda'\lambda'}$,

$$H_T(X, \zeta, t) = A_{++, --} + A_{--, ++}, \quad (5)$$

where $H_T(x, \xi, t)$ has the following properties:

$$\int H_T(x, \xi, t) dx = A_{T,10}(t) \quad (6)$$

$$H_T(x, 0, 0) = h_1(x) \quad (7)$$

and the form factor $A_{T,10}(t)$ gives the tensor charge for $t \rightarrow 0$.¹

In order to investigate more extensively the tensor charge and the possible mechanisms at work in both the partonic and hadronic pictures exclusive electroproduction of π^0 and η on both proton and neutron targets, can be used where a more direct connection between theoretical quantities and observables can be established.

3 Extraction of Tensor Charge from Data

We propose a dynamical mechanism for the process $\gamma^* P \rightarrow \pi^0(\eta) P'$ that allows for a direct extraction of the tensor charge from experiment. The cross section for π^0 electroproduction reads

$$\begin{aligned} \frac{d\sigma}{dt d\phi} &\propto L_{\mu\nu}^{h=\pi^0} W^{\mu\nu} \\ &= \left(\frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt} \right) + \epsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi + \sqrt{2\epsilon(\epsilon+1)} \frac{d\sigma_{LT}}{dt} \cos \phi. \end{aligned} \quad (8)$$

$L_{\mu\nu}^{h=\pi^0}$ is the leptonic tensor, or polarization density matrix, and

$$W^{\mu\nu} = \sum_f J_\mu J_\nu^* \delta(E_i - E_f) \quad (9)$$

¹Notice that $A_{\Lambda\lambda, \Lambda'\lambda'}$, reduces to $\Phi_{\Lambda\lambda, \Lambda'\lambda'}$, Eq.(3), in the forward limit.

where the sum is carried out over all final states, and J_μ is the matrix element of the proton electromagnetic current operator between the initial and final states. Note that the quantity

$$\frac{d\sigma_{TT}}{dt} = W_{yy} - W_{xx} \equiv 2\Re(J_1 J_{-1}^*) \quad (10)$$

can also be written in terms of the helicity amplitudes introduced in Section 2. $d\sigma_{TT}/dt$ enables us to access the tensor charge by taking the $t \rightarrow 0$ limit of the only non-flip helicity amplitude for the process. This is in fact proportional to a combination of unnatural parity exchanges (see Fig.1) that provide the quantum numbers in the t -channel that are necessary to produce a chirality flip and emit the π^0 . Notice that other quantities that provide similar information such as the target transverse polarization asymmetry, A_{UT} , can be considered. These will be discussed in detail in a forthcoming publication.

In this contribution we present preliminary results using both the hadronic and the partonic descriptions, the latter obtained by implementing a recent GPD parametrization¹⁹⁾. A practical extraction of the tensor charge can be obtained by noticing that in either the hadronic or in the partonic, GPD-type, description of *e.g.* $d\sigma_{TT}/dt$, the tensor charges for the different isospin components might be treated as parameters related to the normalization of H_T . Therefore our models can be used to constrain the range of values allowed by the data.

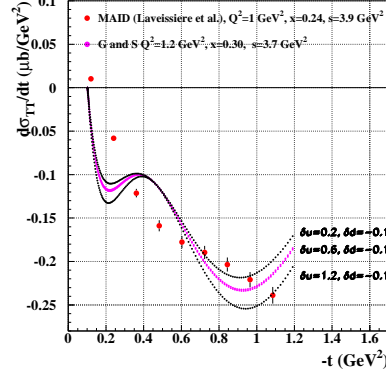


Figure 3: *Experimental determination of the tensor charge for u and d quarks, δu and δd , using MAID data on $d\sigma_{TT}/dt$ (20). The suggested extraction method is explained in the text.*

As an example in Fig. 3 we show a comparison of our Regge model with the MAID (20) parametrization of pion electroproduction data at $s = 4 \text{ GeV}^2$ and $Q^2 \approx 1 \text{ GeV}^2$. The different curves were obtained by varying the values of the tensor charge entering the normalization of the different t -channel exchanges. We expect a variety of new flavor sensitive observables to be extracted from data in the near future using both unpolarized data and asymmetries from transversely polarized proton and deuteron data on π^0 and η production at the higher values of s available at Jefferson Lab. This analysis promises to be a rich area of experimental exploration in the near future.

4 Conclusions

We presented our preliminary results on an alternative method to extract the tensor charge, and its related GPDs from experimental observables such as the structure function $d\sigma_{TT}/dt$ in unpolarized exclusive π^0 electroproduction. Our study uses both a Regge model, and a diquark scheme for the transverse GPD, H_T , which include as parameters the isospin dependent tensor charges.

A feasibility study with members of the Hall B collaboration at Jefferson Lab is in progress.

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